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RESEARCH ARTICLE

Estimating attraction of Syrphidae (Diptera) to flowering plants with interception traps

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Syrphidae with predaceous larvae are important predators of aphids and other insects and can be attracted and maintained in agricultural environments by the addition of flowering plants. Malaise interception traps baited with moveable flowering plants are a novel means of surveying for attractive species and can have the advantages of: (1) homogenising experimental site and plant quality, (2) portability, (3) continuous sampling, (4) capacity to simultaneously capture a broad range of insects (including pests) and (5) no requirement for additional sensory cues to be effective. Six of the 10 species of plants tested were relatively attractive (number of syrphids captured in flower-traps/numbers captured in no plant controls). While flower-traps captured more syrphid species than their associated controls, there were no differences between flower-traps and controls in the sizes (head height) or proboscis lengths of the flies collected. There were no significant relationships between relative attractiveness and flower width or depth or with plant height and floral area. Similarly, mean proboscis length of flies taken in flower-baited traps was not correlated with flower width or depth. The absence of the latter relationship may be due to the inability of an interception trap to distinguish between attraction and attraction-then-feeding.

Keywords: malaise trap; biological control; predator; Aphididae; hoverfly

1. Introduction

Adult Syrphidae, commonly and appropriately called hover or flower flies, consume floral nectar and pollen, and long lists of feeding observations from a variety of plants have been compiled (Tooker, Hauser, & Hanks, 2006). This attention to adult feeding behaviour is due in part to the predatory nature of larvae in the subfamily Syrphinae. Addition of the proper flowering plants to agricultural landscapes can attract ovipositing females whose offspring then control soft-bodied phytophages such as aphids (Bugg, Colfer, Chaney, Smith, & Cannon, 2008).

Syrphids, as opposed to other aphidophages, have a number of advantages as biological control agents. They can locate aphid colonies at relative low densities (Horn, 1981), are voracious feeders with short prey-handling times (Barlow & Whittingham, 1986; Scott & Barlow, 1990) and have high rates of reproduction (Ankersmitt et al., 1986). To concentrate and then conserve syrphid populations, and so bring these advantages to bear, suitable flowering plants should be chosen upon

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criteria that include the resources they contribute to adult longevity and egg production (Laubertie, Wratten, & Hemptinne, 2012). Attractiveness, however, is primary and syrphids as a rule are not equally attracted to all flowering plants (Ambrosino, Luna, Jepson, & Wratten, 2006).

Various means have been used to associate syrphids with particular plants. For the most part, these are observational and include regularly patrolled transects through different types of habitats (Gilbert, 1981) and repeated visits to experimentally controlled flower patches (e.g. Ambrosino et al., 2006). Fluid-filled pan traps have been used to sample among and around flowers (Wratten, Whaite, Bowie, Berry, & Weigmann, 1995), and Haslett (1989) examined pollen in guts to identify fed-upon plants. Here we describe another method of estimating the attractiveness of flowering plants: the use of stationary interception traps (Malaise traps) under which are placed potted plants that can be moved among trap sites. We suggest that such traps might have several advantages over capturing insects on *in situ* flowers:

- (1) *Minimise the influence of differences in microhabitats.* By repeatedly rotating the same plants through the same sites, any environmental differences in trap sites can be recognised and dealt with statistically, and plant quality in each site is homogenised.
- (2) *Continuous sampling.* Since insects are vulnerable to malaise trapping 24 hours a day, captures are not influenced by periodicity in the activity of the flies or in the attractiveness of the plants (although less than daily samples could reveal such patterns).
- (3) *Portability.* Sampling sites and flowers can be rapidly moved to test hypotheses such as ‘syrphids in crops decline with distance from flower patches (MacLeod, 1999)’ or ‘barriers like hedgerows prevent the movement of syrphids among crop fields (Lovei, MacLeod, & Hickman, 1998; Wratten et al., 2003)’.
- (4) *Lack of specificity.* By capturing a wide variety of flying insects, it is possible to monitor the attractiveness of particular plants to potential pests as well as to natural enemies;
- (5) *Sensory neutrality.* Some commonly deployed traps, such as yellow pan traps, emit cues like colour that are themselves attractive (Laubertie, Wratten, & Sedcole, 2006). Yellow colours, for example, could draw insects from other trap locations in transects and influence the spatial interpretation of capture numbers. As interception traps, Malaise traps need not rely on additional cues, and those used in our experiments did not have obvious visual or olfactory attractive cues, although we cannot rule out possibilities such as ultraviolet reflectance.

In the following, first, we tested the hypothesis that Malaise trapping could identify plants attractive to Syrphidae (note that in two of the species examined, plants grew *in situ*, and there was no Malaise trap rotation). Second, we asked whether Malaise trapping could discern a pattern in the relative attractiveness (numbers of syrphids captured with flowers per numbers captured in controls) of different plants. If such a pattern were to be identified, it could suggest what other plants might be candidates for biological control. While colour (Sutherland, Sullivan, & Poppy, 1999), odour (Laubertie et al., 2006) and even marks from previous visitors (Goulson, 1999) are

cues used by foraging Syrphidae to locate flowers, we correlated the width and depth of flowers and the height and floral areas of flowering plants to both the numbers of syrphids captured (relative attractiveness) and to the lengths of their proboscises. Proboscis length has been repeatedly related to preferences for particular flower morphologies (e.g. flowers with deeper corollas are most frequently visited by syrphids with longer proboscises; Gilbert, 1981, 1985; Gilbert, Harding, Line, & Perry, 1985). We discuss the attractiveness of the tested flowers not only to syrphids but also to a group of herbivorous insects and potential pests and argue that floral relationships with nocturnal responders such as moths are easily explored through Malaise trapping. Finally, we examine the shortcomings of Malaise trapping and provide an example of where and why it might be inferior to observational sampling methods.

2. Methods

2.1. Plants examined

The 10 flowering plants included in the present analysis were those of an original 19 species that captured sufficient Syrphidae for analysis ($n > 20$; Table 1; Al-Dobai, Reitz, & Sivinski, 2012; Sivinski, Wahl, Holler, & Al-Dobai, 2011) and included native, established and cultivated species. In northern Florida, USA, natives were originally emphasised in the choice of plant species on the assumption that sympatric natural enemies might have evolved responses to familiar nectar sources. Native and established exotic species had the advantage of being suited to local environments and so were unlikely to require costly inputs for maintenance in agricultural settings. Plants that appeared to be attractive to insects but did not locally self-perpetuate in nature were also included. In addition, flower and plant morphologies presented a

Table 1. The species, common name and family of the tested plants, their origins (C = cultivated, E = established, N = native) and the Julian date of the start of test (see Al-Dobai et al., 2012; Sivinski et al., 2011).

Species	Common name	Family	Origin	Julian date
<i>Agastache</i> hyb.	Blue fortune anise hyssop	Lamiaceae	C	177
<i>Ageratina aromatica</i> (L.) Spach	Lesser snakeroot	Asteraceae	N	319
<i>Buddleja davidii</i> Franch.	Orange eye butterfly bush	Scrophulariaceae	C	212
<i>Conoclinium coelestinum</i> (L.) DC.	Blue mist flower	Asteraceae	N	266
<i>Daucus carota</i> L.	Queen Anne's lace	Apiaceae	E	142
<i>Galium aparine</i> L.	Stickywillly	Rubiaceae	N	83
<i>Monarda punctata</i> L.	Dotted horsemint	Lamiaceae	N	251
<i>Pityopsis graminifolia</i> (Michx.) Nutt.	Narrowleaf silkgrass	Asteraceae	N	272
<i>Solidago fistulosa</i> Mill.	Pine barren goldenrod	Asteraceae	N	247
<i>Stellaria media</i> (L.) Villars.	Chickweed	Caryophyllaceae	E	43

range of flower depths and widths, plant heights and floral areas. Details on plant origin and care are available in Sivinski et al. (2011) and Al-Dobai et al. (2012).

2.2. Curation and identification

All syrphids from a specific sample were removed from 95% ethanol, pinned and labelled with a unique number, location information, the associated flower and treatment (flowers present or control). The length of the proboscis was measured by taking magnified images using a digital camera (Leica D4C450 attached to a Leica M205C stereomicroscope, Leica Microsystems Ltd., Wetzlar, Germany) and making measurements with digital image software (Leica LAS Application Suite, Wetzlar, Germany) (Figure 1).

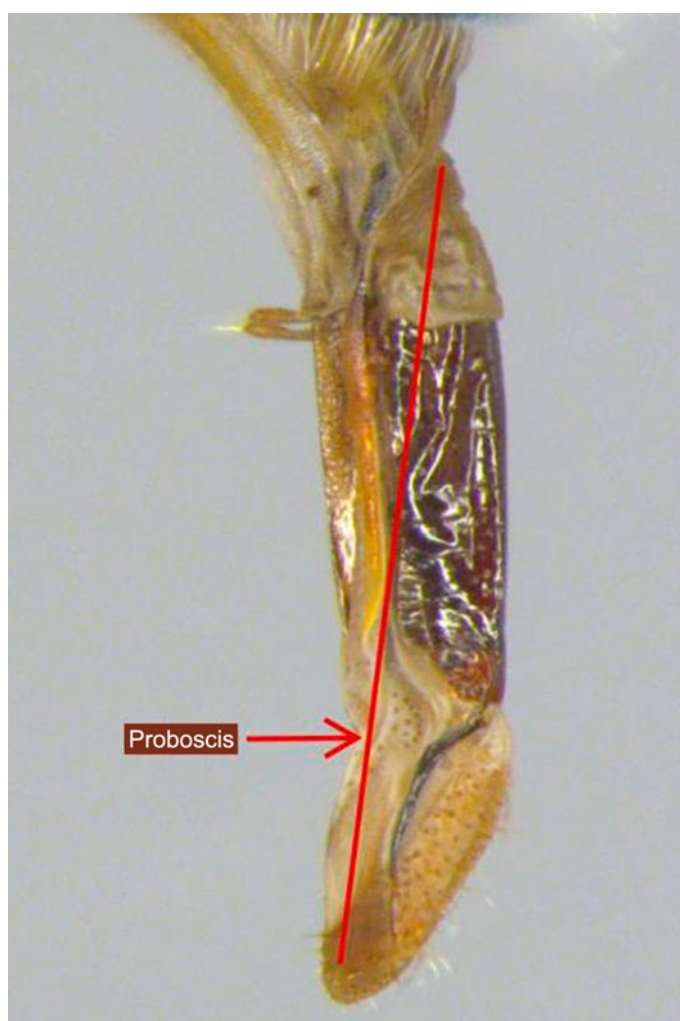


Figure 1. The proboscis of a dried specimen of *Pseudodoros clavatus*. The red line indicates the axis used to estimate proboscis length using a combination of the haustellum and labella.

Species were identified to genera with the guides of Vockeroth and Thompson (1987) and species identification was made with available keys. Specimens were then compared with identified specimens at the Florida State Collection of Arthropods, Florida Division of Plant Industry, Gainesville, Florida, USA. Specimens have been retained in the authors' collections at the USDA-ARS Center for Medical, Agricultural and Veterinary Entomology (CMAVE).

2.3. Malaise traps

The numbers and kinds of syrphids attracted to various flowering plants and their flowerless controls were compared by placing plants and their controls underneath interception traps, i.e. Malaise traps (BioQuip Products Inc. Rancho Dominguez, CA, model 2875D) based on the Townes design [(Ent. News 83:239–247, 1972) (BioQuip Products Inc., Rancho Dominguez, CA, model 2875 WDH) see Al-Dobai et al., 2012; Sivinski et al., 2011 for details]. These consisted of a horizontal mesh barrier 'wall' held in place by two aluminium poles and with shorter mesh perpendicular extensions at both ends. There was also a mesh sloping roof that ran along both sides of the central wall. When erect with their long axis oriented to the south-west, traps were 1.8 metres long by 1.2 metres wide and had an opaque, plastic collecting jar located at the top of one pole. Ethanol (95%) was added to a depth of 2–3 cm in order to preserve the trapped insects.

2.4. Trap sites and flower placement

Traps were erected at set locations on the grounds of the University of Florida Dairy Research Unit in Hague, Florida, Alachua County, in 2008–2009. These sites were along the interface of a diverse forest dominated by water oak (*Quercus nigra* L.) and slash pine (*Pinus elliottii* Englem.) and an understory rich in pokeberry (*Phytolacca americana* L.) and green briar (*Smilax* sp.) and agricultural fields used to grow corn or rye (*Zea mays* L. and *Secale cereale* M. Bleb) depending on the season (in the vicinity of 29° 47.332 N, 082° 25.012 W). Traps were erected in the centre of a 5 m × 5 m piece of black plastic weed cloth to prevent other plants from growing nearby (although see exceptions in trapping design no. 1 in Section 2.5). Wild plants were regularly removed within 3 m of the weed cloth margins (Rohrig, Sivinski, Teal, Stuhl, & Aluja, 2006). For trapping designs no. 2 and no. 3 (Section 2.5) the two or three traps sites were separated by 30–50 m and chosen on the basis of similar environments. Experimental designs no. 2 and no. 3 called for the rotation of 50 individually potted plants or pot-without-plant controls among the sites (Section 2.5). Pots were placed in six tightly packed rows directly underneath the canopy of the Malaise traps, i.e. three rows on each side of the central barrier-wall.

2.5. Sampling designs and analyses

Three different trapping designs were used depending on the availability and location of flowers, and these differed in their capacity to provide unambiguous results (Sivinski et al., 2011). In the order of increasing experimental confidence, these are described in the following sections.

2.5.1. Trapping with flowers *in situ*, followed by their removal

Wild *Galium aparine* L. and *Stellaria media* (L.) Villars grew along the forest/field interface in homogeneous clumps large enough in our estimation ($\sim 5 \text{ m} \times 5 \text{ m}$) to erect Malaise traps in their midst. The three sites used for each species were within $\sim 50 \text{ m}$ of each other. No potted plants were used in these cases, and plants were not rotated among sites. Details on the determination of flowering plant homogeneity within sites are available in Sivinski et al. (2011) and Al-Dobai et al. (2012). As in the experimental designs No. 2 and No. 3 (see below), random samples of flower width, depth and density and plant heights were taken in each patch prior to Malaise trap placement (see details in Al-Dobai et al., 2012; Sivinski et al., 2011). In one of the three sites, the flowering plants were mowed down and the ground covered with a $5 \text{ m} \times 5 \text{ m}$ sheet of plastic weed cloth. Simultaneous collections in the single mowed and the two plant-containing sites continued as long as practical (at least 1 week, generally time was limited by projected declines in target-plant flowering). Following this collection, one of the two flower patches was mowed down and covered by a $5 \text{ m} \times 5 \text{ m}$ sheet of weed cloth. Collections then continued on all the three sites for the same length of time as the pre-flower-removal collections (see Al-Dobai et al., 2012; Sivinski et al., 2011). Syrphids captured in the site that had flowers during the first collection period but that had its plants removed prior to the second could then be compared to the following: *Numbers captured in the site that never had flowers*. If syrphid capture numbers changed in the site where flowers were mowed down prior to the second collection period to a greater degree, than captures in the site where there had never been flowers, then it could be inferred that the flowering plants had influenced the rate of insect capture. *Numbers of insects trapped in the site left in bloom after the manipulated site was mowed down*. This comparison of changes in insect capture could reflect any changes due to floral abundance/attractiveness. Data analysis was by contingency χ^2 test, with site (continuous flowering plants available, plants removed halfway through collecting period and no flowering plants ever present) and collection period (pre-flowering plant and post-plant removal in the modified site) defining the contingency table (Zar, 1974; for further details see Al-Dobai et al., 2012; Sivinski et al., 2011). Because plants with and without flowers were not examined separately, significant differences in captures did not demonstrate floral attraction in the strictest sense. Other plant parts and plant-induced micro-environments, e.g. shade, wind-shelter and oviposition opportunities, could also be responsible for higher trap catches relative to sites without plants.

2.5.2. Rotation of flowering plants and no plant controls between two trap sites

Fifty individually potted flowering plants of a particular species were rotated among Malaise traps erected on two weed cloth prepared sites three to six times (6 to 12, 48-hour long collection replicates per species). Sites were distinct from experimental design No. 1 and previously described. No-plant controls consisted of 50 pots with soil and were initially placed in rotation under an alternate Malaise trap. The three plant species examined in this manner were: *Agastache* hybrid, *Ageritina aromatica* (L >) Spach and *Buddleja davidii* Franch. Plants-in-flower were not examined separately from the plants-without-flowers so that significant differences in captures were best interpreted as flowering plant, not floral, attraction. The mean numbers of

syrphids collected in traps with and without plants were compared by *t*-tests, using the Satterthwaite method in cases of unequal variances (SAS Inst., 2004).

2.5.3. Rotation of flowering plants, non-flowering plants and no plant controls among three trap sites

This design provided the best estimation of floral attraction by simultaneously comparing a blank (no plant) control with plants both in and out of flower. The five species examined were the following: *Conoclinium coelestinum* (L.) DC., *Daucus carota* L., *Monarda punctata* L., *Pityopsis graminifolia* (Michx.) Nutt. and *Solidago fistulosa* (L.) Villars. As above, 50 potted plants of a particular species were rotated among set sites, in this case, three sites that included those used in trapping protocol No. 2. There were six to nine replications per species, each typically 48 hours long. When it was necessary to remove flowers from plants serving as ‘no-flower’ controls, a comparable amount of tissue was cut from those that retained their flowers. During the course of the experiment, flowers on individual plants changed in number and location, and those whose flowering substantially declined were replaced, typically with control plants coming into flower (and vice versa). The impacts of pseudoreplication were mitigated by between treatment-cohort exchanges and individual plant plasticity. The relatively large numbers of plants in each cohort were useful in capturing the variability within the entire experimental plant population. Syrphid captures for each plant condition (a particular species of plant in flower, out of flower, and pot with no plant) were compared by ANOVAs followed by Waller’s mean separation test (Proc ANOVA; SAS Inst., 2004).

2.6 Floral and plant characteristics and their relation to captures

Since flower/floret width and depth of flowers might influence access to nectar, these were measured in 10 randomly chosen blossoms, one from each of the 10 randomly chosen plants of each species (details in Al-Dobai et al., 2012; Sivinski et al., 2011). Depth was considered the distance from the margin of the flower’s petals to the underside of the calyx. Width in radially symmetrical flowers was the corolla diameter and in bilaterally symmetrical flowers, the shorter of the two axes; i.e. the axis most likely to control access. Flower density was estimated using an open plastic frame randomly tossed onto the plants under a Malaise trap and then counting all the flowers within its boundaries. ‘Floral area’ was calculated as the area of a flower/floret multiplied by flower density (for details see Al-Dobai et al., 2012; Sivinski et al., 2011). In the case of Asteraceae, the floral area included the additional width provided by the ray flowers (the apparent ‘petals’). Plant height was randomly sampled (by blind pointing) 10 times and in the case of potted plants the height of the pot was included in total height. There was no effort made to measure the different variables of the same plants. Measurements are available in Sivinski et al. (2011). Separate regressions examined relationships among syrphid capture ratios (Syrphidae captured in association with a particular flowering plant divided by the number captured in controls and (1) flower characteristics (width and depth) and (2) plant characteristics (height and floral area) (SAS Inst., 2004). Capture ratios were used in regressions because plants were exposed in traps at different times of the year, during which different insects were likely to be present and occur at different

densities. The ratio expresses the attractiveness of the plant relative to the control and not absolute insect numbers and thus allowed comparisons of the various flowers.

3. Results

Traps containing six of the 10 species of tested plants captured more Syrphidae than their controls (Figure 2). In a seventh species, *Conoclinium coelestinum*, the difference between the flower-trap and the no plant control bordered on significance, and it was included as an attractive plant in the analyses below. A total of 1670 syrphids were collected, and for the most part, these consisted of 19 species (Table 2; sexes and conditions of capture are listed in Table 3). None of the measured characteristics of the flowers (width, depth and their quadratics) or the plants (height and floral area and their quadratics) were related to relative attractiveness [numbers of flies captured on flower-traps/numbers captured on no plant controls; $F(\text{flower width and depth}) = 0.64$, $df = 9$, $p = 0.69$; $F(\text{height and floral area}) = 4.35$, $df = 9$, $p = 0.09$]. The capture of 486 *Copestylum trivittatum* Thompson in traps containing *Agastache* hyb. had little significance for biological control since the larvae are likely to develop in decaying plant matter. If the *Agastache* outlier is removed, the relationship between relative attractiveness and floral area borders on significance ($F = 3.91$, $df = 8$, $p < 0.09$).

In attractive plants, more species of syrphids are captured in traps erected over flowering plants than in no plant controls [Table 3; mean (flower) = 6.6 vs. mean (control) = 3.1, $T = 3$, $p = 0.05$]. However, this diversity did not result in any significant differences in size of captured flies, e.g. head height [Table 2; mean (flower) = 2.6 (0.2) vs. mean (control) = 2.7 (0.2), $t = 0.46$, $df = 12$, $p > 0.65$], their mouth length [mean (flower) = 1.14 (0.1) vs. mean (control) = 1.14 (0.2), $t = 0.04$, $df = 12$, $p > 0.97$] or their mouth length relative to head height

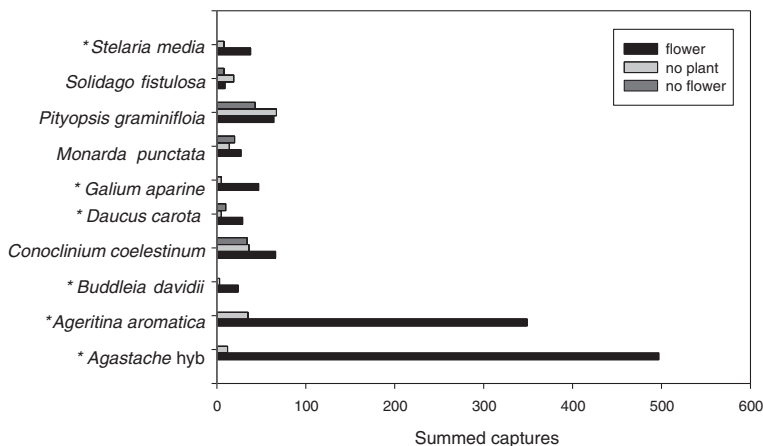


Figure 2. The total numbers of Syrphidae caught in traps with flowering plants, with plants without flowers and without plants. In six of the 10 examined plant species, there were significantly greater captures in flower-associated traps than in controls. There were no instances of significantly more captures in controls. Asterisks (*) denote significant differences.

Table 2. Mean (stderr) tongue length, head capsule height and tongue length relative to body size (tongue length/head height) of the most commonly captured species of Syrphidae.

	Tongue length (mm)	Head height (mm)	Relative tongue length
<i>Allograpta exotica</i> (Wied.)	0.90 (0.07)	2.42 (0.06)	0.37 (0.03)
<i>Allograpta obliqua</i> (Say)	0.90 (0.03)	2.42 (0.03)	0.37 (0.01)
<i>Chalcosyrphus metallicus</i> (Wied.)	0.96 (0.02)	2.56 (0.06)	0.37 (0.001)
<i>Copestylum trivittatum</i> Thompson	1.80 (0.08)	3.34 (0.04)	0.54 (0.03)
<i>Eupeodes americanus</i> Wied.	1.31 (0.07)	3.35 (0.07)	0.39 (0.02)
<i>Ocyptamus costatus</i> Say	0.78 (0.06)	2.26 (0.12)	0.35 (0.04)
<i>Ocyptamus cylindricus</i> (Fab.)	0.61 (0.05)	2.49 (0.04)	0.24 (0.02)
<i>Ocyptamus fuscipennis</i> (Macquart)	0.67 (0.06)	2.52 (0.06)	0.27 (0.03)
<i>Palpada agrorum</i> (Fab.)	2.04 (0.04)	3.93 (0.01)	0.51 (0.01)
<i>Palpada furcata</i> (Wied.)	1.89 (0.04)	3.63 (0.11)	0.52 (0.005)
<i>Palpada pusilla</i> (Macquart)	2.21 (0.08)	3.93 (0.06)	0.56 (0.03)
<i>Palpada vinetorum</i> (Fab.)	2.09	4.58	0.46
<i>Pseudodoras clavatus</i> (Fab.)	1.70 (0.05)	2.59 (0.03)	0.65 (0.01)
<i>Toxomerus boscii</i> Macquart	1.09 (0.02)	1.85 (0.04)	0.59 (0.004)
<i>Toxomerus floralis</i> (Fab.)	0.85 (0.02)	1.80 (0.03)	0.47 (0.02)
<i>Toxomerus geminatus</i> (Say)	1.03 (0.03)	2.12 (0.03)	0.49 (0.02)
<i>Toxomerus marginatus</i> (Say)	0.99 (0.04)	1.74 (0.05)	0.57 (0.02)
<i>Toxomerus politus</i> (Say)	0.87 (0.02)	2.30 (0.05)	0.38 (0.009)
<i>Toxomerus verticalis</i> (Curran)	1.08 (0.08)	2.04 (0.11)	0.54 (0.06)

[mean (flower) = 0.44 (0.02) vs. mean (control) = 0.46 (0.06), $t = 0.95$, $df = 12$, $p > 0.35$]. There was no significant relationship between mean tongue length and body size (as estimated by the height of the head) of the flies captured in traps associated with significantly attractive plants and the width and depth of flowers [F (tongue length) = 0.55, $df = 6$, $p = 0.76$; F (head height) = 0.32, $df = 6$, $p = 0.86$].

4. Discussion

In the course of the experiment, 1670 Syrphidae were captured in traps over flowering plants and their controls. Four hundred ninety-six of these were the cristaline species *Cheiracanthium trivittatum* collected in traps containing *Agastache* hybrid, with another 12 in its no plant control. This was by far the highest relative attractiveness (number of flies taken in flower-traps/number in control) but is of no biological control significance since the larvae are likely saprophages (Martínez-Falcón, Durbán, Lattore, Antón, & de los Ángeles, 2011). Other plants had substantial levels of relative attractiveness to syrphine species with biological control potential, notably *A. aromatica* (*Allograpta obliqua* [Say], *Eupeodes americanus* Wied., *Ocyptamus fuscipennis* [Macquart], *Toxomerus floralis* [Fab.]), *C. coelestinum* (*Toxomerus politus* [Say]) and *G. aparine* (*Toxomerus boscii* Macquart). The latter is mentioned specifically by Bugg et al. (2008) as one of the relatively unknown ‘road-side’ plants that might have control potential. Overall, of the 10 plants examined, six

Table 3. Significantly attractive flowering plants and the Syrphidae most commonly captured.

	<i>Agastache</i>	<i>A. aromatica</i>	<i>B. davidii</i>	<i>C. coelestinum</i>	<i>D. carota</i>	<i>G. aparine</i>	<i>S. media</i>
<i>Allograpta exotica</i>		F1♀1♂			NF1♀ F2♀4♂		
<i>Allograpta obliqua</i>		C1♀ F76♀16♂*			C2♀ NF3♀2♂ F10♀5♂	Fpre7♀2♂ Fpost2♀ Fpre1♂ Fpost2♀	Fpre5♀2♂ Fpost1♀
<i>Chalcosyrphus metallicus</i>	F1♂	C2♀1♂ F1♀					
<i>Copestylum trivittatum</i>	C9♀3♂ F♀243♂ 251*	F1♀3♂	C1♀ F7♀ 2♂		C1♂ F1♀		Fpost1♀
<i>Eupeodes americanus</i>		C10♀ F36♀2♂*				Fpre3♀11♂ Fpost8♂	Fpre1♂
<i>Ocyptamus costatus</i>		F3♀10♂					
<i>Ocyptamus cylindricus</i>		F1♀	F4♀2♂				
<i>Ocyptamus fuscipennis</i>	F14♀3♂	F30♀23♂*					
<i>Palpada agorum</i>		F4♀4♂	F1♀				
<i>Palpada furcata</i>	C1♂	F4♂			F1♀1♂		
<i>Palpada pusilla</i>		F10♀7♂	F1♀1♂				
<i>Palpada vinetorum</i>		F4♀					
<i>Pseudodoros clavatus</i>	F3♀1♂	F4♀4♂	F1♂				
<i>Toxomerus boscii</i>		C1♂ F6♀				Fpre12♀11♂ Fpost1♀2♂* Fpre1♀	
<i>Toxomerus floralis</i>		C8♀3♂ F47♀ 22♂*	F1♂		C1♀		
<i>Toxomerus geminatus</i>		F2♀		C1♂		Fpre3♀3♂ Fpre2♀2♂	Fpost1♀
<i>Toxomerus marginatus</i>		C2♂ F11♀4♂	F3♀			Fpre1♀	
<i>Toxomerus politus</i>		C2♀3♂ F3♀ 11♂		C18♀16♂ NF17♀ 15♂ F33♀30♂*	C1♀ NF5♂ F1♀ 2♂		
<i>Toxomerus verticalis</i>		F3♀3♂	F1♀		F1♂		

C = no plant control, NF = no flower control, F = flower, Fpre = preliminary captures where flowers were subsequently removed, Fpost = captures following removal of flowers. Captures in *G. aparine* and *S. media* sites left in bloom or never containing flowers are not included. Although not significantly attractive *C. coelestinum* was added to the table because flower captures bordered ($p=0.10$) on significance. An asterisk (*) in a cell indicates a significant capture of that syrphid species in traps associated with that plant (no analysis was performed unless at least a sum of 20 insects was present in the cell). Species of the subfamily Syrphinae have predaceous larvae and are potential biological control agents. These and their related data are presented in bold letters.

were significantly attractive to Syrphidae in general, and this number could be raised to seven with the addition of the borderline case of *C. coelestinum*. There was no significant pattern between flower (width and depth) or plant (height and floral area) characteristics and relative attractiveness that would have predicted which plants were likely to be attractive prior to future experiments. However, the relationship between floral area and relative attractiveness bordered on significance and is a component of attractiveness to natural enemies in general (Fiedler & Landis, 2007a) and parasitic Hymenoptera in particular (Sivinski et al., 2011).

There are several plants frequently employed in conservation biological control research and practice (Ambrosino et al., 2006; Hogg, Bugg, & Daane, 2011; Laubertie et al., 2012), including phacelia (*Phacelia tanacetifolia* Benth), coriander (*Coriandrum sativum* L.), buckwheat (*Fagopyrum esculentum* Moench) and sweet alyssum (*Lobularia maritima* L. Desv.). These same plants attract and/or feed natural enemies other than Syrphidae (Lee & Heimpel, 2005; Rohrig et al., 2006; Vattala, Wratten, Phillips, & Wäckers, 2006), and the same can be said for many of the plants tested in the present study (Al-Dobai et al., 2012; Sivinski et al., 2011). Such additional biological control benefits might influence which plants are chosen for landscape modification biological control, but attractiveness to pests, either the target or other species, is another important variable. For example, Lee and Heimpel (2005) considered this problem when planting *F. esculentum* borders around cabbage (*Brassica oleracea* L.) fields and found that the flowers had no effect on the numbers of three Lepidopteran pests. On the other hand, among a wide variety of mostly Michigan-native, perennial plants, those that were attractive to natural enemies were generally more attractive to hemipteran, coleopteran, orthopteran, lepidopteran and dipteran herbivores (Fiedler & Landis, 2007b). For an example in the present study, nine plants captured sufficient number of both Lepidoptera and Syrphidae for eventual comparison (Sivinski, unpublished data). A preliminary analysis of the ranked relative attractiveness of these plants to both Syrphidae and Lepidoptera found that plants such as *G. aparine* and *D. carota* attracted relatively high numbers of natural enemies but relatively few moths. We believe that such relationships would be more difficult to determine without the Malaise traps intercepting nocturnal Lepidoptera.

While Malaise traps may have been convenient in contrasting the attractiveness of flowers to both syrphids and Lepidoptera, there are situations where they are likely inferior to sampling methods such as direct observation. One such instance may have been the failure to replicate the frequency-of-visitation relationship between flower-corolla depth and fly-proboscis length (Gilbert, 1981). In this case, an interception trap cannot distinguish between attraction and attraction-then-feeding. For example, a flower such as *P. tanacetifolia* may be attractive but have such a deep corolla that many parasitic Hymenoptera and short-tongued syrphids are unable to exploit its abundant nectar (Vattala et al., 2006), although pollen could still be consumed (Holland, Thomas, & Courts, 1994). Flies might have been attracted to a floral odour and then captured in Malaise traps when they would not have stayed to feed.

In conclusion, Malaise traps with flowers often captured more species and individuals of Syrphidae than those without. While they can have the advantages of homogenising experimental site and plant quality, portability, continuous sampling and capacity to capture a broad range of insects and no requirement for additional

sensory cues to be effective, they do have shortcomings such as an inability to identify the behaviour the flies were engaged in at the time of their capture.

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